JOURNAL OF AGRICULTURAL RESEARCH

VOL. XVI WASHINGTON, D. C., MARCH 17, 1919 NO. 11

FUSARIUM-BLIGHT OF POTATOES UNDER IRRIGATION

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HISTORY OF FUSARIUM-BLIGHT

The Irish potato (*Solanum tuberosum*) has been one of the most profitable crops grown in the Greeley district of northern Colorado. In this fertile, irrigated section, one of the oldest in the country, the potato gave large yields for many years before any serious setbacks occurred. From 1908 to 1912 the inroads of disease threatened the industry severely, and in 1911 and 1912 the crops were failures. In 1915 a laboratory was established at Greeley for the study of potato troubles, but since that year the yearly losses have been light. Fusarium-blight has been present, however, as a conspicuous malady.

Fusarium-blight, or potato-wilt, is well recognized in nearly all the potato-growing regions of the country, except in the extreme Northeastern States. It is caused most frequently by the fungus *Fusarium oxysporum* Schlect., though other species of this genus have been found involved. In 1899[1] Smith (*15*)[2] first proved that species of this genus would cause plant-wilts, and in 1904 Smith and Swingle (*16*) described a potato-wilt and tuber-rot due to *F. oxysporum*. It was believed by them that the *F. solani* of Pizzigoni (*10*) and of Wehmer (*17*) was identical with their species. The confusion which existed over the definition of species was largely removed by the taxonomic investigations of Appel and Wollenweber (*1*), Carpenter (*2*), Sherbakoff (*13*), and Wollenweber (*20*). Manns (*6*), Orton (*9*), Pratt (*11*), Wilcox (*18*), and others have continued to reveal the great losses which species of Fusarium cause in the potato industry and have suggested methods of control.

[1] Smith, Erwin F. The watermelon disease of the south. (Abstract.) *In* Proc. Amer. Assoc. Adv. Sci. 43d Meeting, 1894, p. 289-290. 1895.

The following papers are likewise contributory:

Smith, Erwin F. The spread of plant diseases. A consideration of some of the ways in which parasitic organisms are disseminated. *In* Trans. Mass. Hort. Soc. 1898, pt. 1, p. [illegible]. 1899.

——— The fungous infestation of agricultural soils in the United States. *In* Sci. Amer. Sup., v. 48, no. 1236, p. [illegible]. 1899.

[2] Reference is made by number (italic) to "Literature cited," pp. [illegible].

PREVALENCE AND LOSS

Fusarium-blight has not appeared to persist in any one locality. Its visitations are sporadic. The losses are, therefore, not to be estimated in concrete terms. In Colorado in 1917, a favorable season for the crop, about 46,000 acres of potatoes were grown. It is estimated that, owing to disease, 10 per cent of the acreage planted gave either reduced yield or no yield. In a good field most of the diseased plants soon pass out of sight and make no impression on the casual observer. Yet these occasional diseased plants probably resulted in a loss of 500,000 bushels in Colorado alone. At other times the disease spreads more generally, and whole fields go down and are lost. Since the part of *Fusarium* spp. in the creation of disease depends largely on environmental factors, it is important to note that the conditions which prevail in Colorado do not exist in the same way in other places. The descriptions of diseases caused by species of Fusarium already published do not, therefore, closely apply to Colorado, because the climate, coupled with the soil conditions and irrigation practice existing there, creates a condition unknown in the East, where most of the work on *Fusarium* spp. has been done.

DESCRIPTION OF DISEASED PLANTS

The common manifestations of the disease are a wilting and rolling of a few leaves, followed quickly, slowly, or intermittently by the wilting of the remainder and usually the premature death of the foliage. Occasionally a single leaf will wilt, turn yellow, and die, whereas the remainder of the plant may continue healthy throughout thes eason. Frequently one of the two or more stems of a hill wilts and dies, while the others remain turgid and healthy. The time of appearance varies greatly. It may be noticeable when the first leaves appear or at any time throughout the season up to maturity. A faint lightening in the color of the plant may indicate a gradual attack, and when the attack is severe, a large plant may pass from health to complete collapse in two days. Late in the season, three or four weeks before frost, plants turgid and unwilted, are found upon which all the upper leaves are rolled. They are a little lighter in color than normal plants, and have often been designated by the uninitiated as being diseased by leafroll. Plate 41,B, shows a plant of this type; the leaves are rolled, but show no wilting. These plants may continue to lighten in color, the leaves to roll, and gradually to die. These conditions are due to the presence of Fusarium mycelium in the vascular tissues of the stem. Plate 40,D, shows a plant on which the leaves have rolled and are gradually dying. What has actually happened in this plant is that the fungus has created a physiological drouth which has extended over a long period. Upon examining plants in the earlier stages of wilt, the stem and roots are usually found clean and apparently healthy, but the seed piece has rotted, and remains

as a wet, jelly-like mass. Later in the season the seed piece practically disappears, and the roots and stem may become blackened and decayed. At first the stems may be wet and slippery, but in time they become dry, brittle, and friable. The main and lateral roots of plants having rolled leaves late in the season are often normal in external appearance.

The term "Fusarium-blight" is preferred for the disease, because it is more applicable to all its stages. The name "Potato-wilt" has been used elsewhere, and so has "Fusarium-wilt," but their use is likely to cause confusion with other diseases, and are not accurately descriptive, as they limit the picture to wilt. As will be seen later, the term "Fusarium-blight" covers the diseases much more accurately.

INOCULATION EXPERIMENTS

The cause of Fusarium-blight is *F. oxysporum*. Other species of Fusarium are capable of producing similar phenomena in the potato plant, but *F. oxysporum* is the species commonly found in isolation cultures from diseased material.

At various times cut potato tubers have been inoculated with spore susspensions of *F oxysporum* and kept in moist chambers in the laboratory. These tubers were always destroyed by the action of the fungus, while controls made in the same manner with sterile water remained normal.

On July 17, 1917, six smooth Early Ohio tubers were given surface sterilization. Each tuber was cut into two equal parts, one half being reserved for control and the other half for fungus inoculation. Glass rings of the Van Tieghem cell type were smeared on the edges with petrolatum and put down on the center of the cut surface of the tuber after it had dried slightly from cutting. Two drops of a heavy spore suspension from an authentic pure culture of *F. oxysporum* were placed within the ring under aseptic conditions, and the cell closed with a cover glass. The controls were prepared the same way with sterile water. These seed tubers were taken to the field and planted in a row at a depth of 3 inches, where they were subjected to natural field conditions rather than to the artificial environment of a flat. On August 13, 1917, twenty-seven days after inoculation, the ground was carefully scraped away and the plants taken up. The six seed pieces inoculated with the fungus were badly decomposed. Four of them had disintegrated to a completely rotten mass. The other two had sprouted, and a small firm area remained by the stem. *F. oxysporum* was recovered from these in pure culture. The controls were uniformly healthy throughout. Plate 37, A, illustrates a control and a diseased seed piece of this experiment.

On August 10, 1917, fifteen tubers were cleaned and sterilized. They were cut as before, and one half of them were inoculated with a spore suspension of *F. oxysporum* dropped into glass rings, the other half being treated as controls. Five inoculated and five control seed pieces were planted together in sterilized soil in each of three flats. They were

watered with sterile water. The flats were set on the edge of a field, where ordinary weather factors would act as normally as possible. These flats were noted finally on September 8, 1917. The control plants were healthly throughout, with normal foliage and stems 10 inches long. In the first flat only one tuber of the inoculated seed sent up a pair of sprouts. One of these was dead and the stem blackened for 2 inches above the ground. Although the seed piece was thoroughly decayed, the other sprout appeared healthy, as shown in Plate 37, B, It is characteristic in every respect of the field blight. A closer view of the seed piece, together with a control seed piece from the same flat, is shown in Plate 37, C. In the second flat two seed pieces failed to germinate, owing to decay. One was dead, and the stem was blackened. In the third flat one seed piece failed to germinate, while four sent up sprouts. These had all wilted thoroughly, though death had not yet occurred. None of these plants had been subject to frost. Isolation cultures were made from all the diseased plants from the three flats, and *F. oxysporum* was recovered in pure culture in each case.

On September 9, 1917, three flats were prepared for inoculation. Sterile soil was used. Seed pieces of the Pearl variety were inoculated with a spore suspension of *F. oxysporum* in the usual way. The spore suspension was made from cultures taken from the diseased seed pieces of the inoculation experiment of July 17. No controls were made, because of lack of space. Owing to the lateness of the season, these flats were taken to Fort Collins, Colo., where, through the courtesy of the Horticultural Department of the Agricultural College, they were placed in the greenhouse. The plants were not seen until November 3, at which time all were dead with the exception of three plants, then about to die.

On August 13, 1917, nineteen whole tubers which had been planted in the field for three weeks and which had sent up sprouts were inoculated. Fourteen of them were inoculated with a spore suspension of *F. oxysporum* poured into glass tubes entering the epidermis of the tuber; five were treated with sterile water as controls. In each case the plant had a healthy, vigorous start. On September 9 the plants were taken up and examined. The seed pieces of the controls were sound and the plants healthy; seven inoculated plants were healthy, though the seed piece was decayed; the other seven were wilted, the stem was blackened, and the seed piece was thoroughly decayed.

On August 10, 1918, sixty-one plants planted in sterile soil in flats were inoculated with *F. oxysporum*. Sixteen plants in flats in sterile soil were treated as controls. The method of handling was different from that used before. The seed pieces had been planted with the cut surface turned up, about a month previously, and the flats left in a cool place. They were watered periodically with sterilized water. By August 10 the

plants had germinated and sent up strong, vigorous sprouts. The seed pieces were solid and unusually well calloused. For the purpose of inoculation the soil was scraped away, and a small core about 1 cm. long was taken out of the upper surface of the seed piece with a small coring tool. The pit made by the removal of the core was filled with a spore suspension of *F. oxysporum* and closed with a cover glass smeared with petrolatum. The controls were treated in the same manner, except that the pit was filled with sterile water. For the next 20 days the flats were exposed to approximately field conditions. The experiment was discontinued on August 30. At that time the inoculated plants had wilted to the ground, while the control plants were normal. Upon examination of the underground parts of the inoculated plants the seed pieces were found to be wholly decayed, and the main root was infected. The roots were not destroyed nor was the main root decayed, but the vascular tissue was woody and filled with mycelium. Isolation cultures made from 40 of the inoculated plants gave *F. oxysporum* in pure culture.

INOCULATIONS ON MATURE PLANTS

On August 13, 1917, inoculations were made on Early Ohio potato plants in the field for the purpose of approximating the disease in its mature stage. The plants were in good soil and had shown no signs of blight from natural infection, though the seed pieces had been attacked. The method employed was very simple. The soil was carefully scraped away from the stem to a depth of 3 or 4 inches, and a slit was made with a scalpel lengthwise through one stem of the plant. A wedge of melilotus stem upon which *F. oxysporum* had been cultured, and which bore mycelium and spores plentifully, was inserted in the slit, and the whole being covered with soil. Forty-six plants were inoculated with the fungus, and 26 were treated as controls. On September 18 these plants were taken to the laboratory for examination. All of the plants had two or more stems, but in the case of the plants inoculated with *F. oxysporum* only the treated stem showed any injury. The plants treated as controls recovered from the mechanical injury, and the wound healed. Plate 38, B, shows a control plant and the method of inserting the wedge. Of the inoculated plants 3 were lost, 4 showed no infection, 2 showed weak or doubtful infection, and 37 showed positive infection. Stems showing infection were typical of the natural blight in every respect. The stems were dead, blackened, and shattered in most cases. Plate 38, A, illustrates two stems of the same plant; the stem at the left was inoculated; the one at the right was not, and shows no injury. Of the 37 stems showing positive infection 20 were selected at random and isolation cultures made. These yielded pure cultures of *F. oxysporum* in 18 cases, the 2 others being badly contaminated.

MODE OF INFECTION

Hitherto infection of potato plants by *F. oxysporum* through the root hairs and small rootlets has been accepted as the usual method. Smith and Swingle (*16, p. 13*) said this occurred, and Manns (*6, p. 306*) reasserted the fact. In case of the cowpeas and cotton, Orton (*7, p. 10; 8, p. 8*) found this manner of infection in both cases. Cromwell (*3, p. 425*) supposed root infection to be the means of entrance of *Fusarium tracheiphilum* Smith, causing the wilt disease of soybean. Jones and Gilman (*4, p. 7*) found the roots of cabbage to be attacked by Fusarium. These numerous instances would call for careful examination of the roots of infected plants. During the years 1916 and 1917, in only 6 plants out of many hundreds examined was this method of infection determined as probable in the case of fusarium-blight of the potato in the Greeley district. In 1918 the soil temperature at a depth of 6 inches was 6° F. above the average for the month of June of the preceding two years. Plants of the Charles Downing variety, planted during the last of May or early June, were badly diseased in some fields by being attacked through the fine roots and root hairs by *F. oxysporum*. This one variety was more severely attacked than any other, even in fields containing several varieties. Most other varieties were not assailed in this manner at all, except a few scattering Early Ohio plants. Higher temperatures seem to be necessary for root infection.

Infection from seed tubers containing the Fusarium organisms in the vascular bundles has been very seldom found. Wollenweber (*19, 20*) has shown that *F. oxysporum* overwinters in potato tubers, where it causes the familiar vascular discoloration. With the sprouting of the eyes when the seed piece is planted the organism infects the new plants and presumably causes wilting and death. One of the most extensively advocated control measures has been aimed to avoid this kind of infection. No trouble has been experienced with this method of infection in the last three years. Field experiments tending to show the nonseverity of this method of infection will be given below.

SEED-PIECE INFECTION

In the Greeley district and in other parts of Colorado potato seed pieces become infected with the Fusarium organism from the soil. The cut seed is vastly more liable to attack than the whole seed, and the decay following infection will begin two or three days after planting. It is justifiable to assume that in the average field nearly all cut seed pieces are infected. Fields have been examined in which hundreds of seed pieces were dug a few days after planting, and less than 5 per cent were found to be free from infection. The infection occurs through the large open wound of the cut surface, lightly protected by callus. The interior loose parenchyma at the center of the tuber, farthest from the active tissue of the vascular

region, is the weakest and least protected. There is a difference in the susceptibility of seed of different varieties, but what seems more important is that seed of the same variety from different sources varies greatly in its power of resistance. The rot following infection may be swift, and the fungus will destroy the seed piece before germination begins.

Plate 37, E, illustrates a seed piece upon which no eye has germinated, though the piece is nearly destroyed by rot. In this illustration two dark spots are to be noted in the vascular region, denoting vascular infection; yet no decay originated at that point. When the decay is slower, the seed germinates and sends up a vigorous shoot. Plates 37, D, and 38, D, illustrate cases of germination followed by seed-piece rot. The region adjacent to the active tissue is the last to decay because it is more resistant and because the decay begins in the loose parenchyma and advances toward the germinating point or place of attachment of the shoot. Where decay is delayed sufficiently to allow germination to take place, the decay works slowly through the active region, or it may stop temporarily. Plate 37, D, illustrates how the decay is delayed nearest the growing part and how it advances evenly toward this region. Plate 39, D, illustrates the base of a plant the seed piece of which had decayed thoroughly. The stem is cut away, showing the healthy tissue within and the absence of the parasite. The general good health of the roots should also be noted.

Some plants appear to grow normally for a few weeks, after which symptoms of disease begin to appear. The color may or may not change, and the leaves may show curling, rolling, or wilting. One lower leaf may turn yellow, wilt, and fall, while the remainder of the plant is a picture of health. In a single hill containing two or more sprouts the tip of one may wilt and the other remain healthy. Plate 40, C, represents a plant consisting of two stems, one of which is healthy, the other wilting. The stem at the left will die, while the stem at the right may live through the season and yield normally. Upon taking up such a plant the decay of the seed piece will be shown to have advanced toward and into the wilted stem, while in all cases the root system is healthy in every branch. Plate 40, B, shows the top of a plant consisting of three stems. The top leaf and the one below it on the same stem are wilted. Neither the other leaves nor the color of the plant indicated anything abnormal. Plate 39, C, shows the seed piece and the three stems of the tops illustrated in Plate 40, B. The wilted leaf shown in Plate 40, B, is on the middle stem pictured in Plate 39, C, which is at the center of the decay. The stem at the left, healthy on Plate 40, B, is here shown with a slight sound area remaining in the seed piece. A stem which shows these symptoms in early summer when conditions are favorable may not at once succumb, but is usually doomed to an early death. Plate 39, B, shows a young plant in which the decay advanced continuously from the seed piece into

the stem. Many plants are to be found which show the violent symptoms, wilting, drooping, and death, within a few days.

The great majority of plants in a field may advance to late maturity with no visible signs of Fusarium-blight. Entire fields have been observed which showed natural wilting caused by delayed irrigation; wet periods may occur, owing to excessive rain following an irrigation; and either of these conditions are conducive to the increased activity of the fungus, though recovery is possible and often occurs. In an entirely healthy field at any period of the season conditions may arise in which the blight gains the ascendancy, the plants wilting and dying in the course of a week. This may happen as late as September, yet infection did not occur immediately before the appearance of wilt, as the fungus had been present since the time of planting.

Whole seed is protected by a sound epidermis underlain by an active vascular tissue, the best protection the seed may have. Whole seed germinates quickly and establishes a sound, vigorous plant weeks before the seed piece has been destroyed by fungi, and the plant becomes liable to attack. It is not unusual for whole seed to remain sound through the growing season, though the ultimate death of the nongerminated eyes, the worn-out vitality of the vascular region, and the dead epidermis make infection possible. Injuries in handling or planting, such as are received from picker planters, render infection comparatively easy. Clipping the stem end to inspect for vascular infection is a most reprehensible practice, as it breaks the epidermis and makes a wound in that part of the tube, tissue which is lowest in vitality and least in the power of self-protection.

OCCURRENCE OF THE CAUSAL FUNGUS

In the case of seed pieces which obtained a favorable start and sent up sprouts the decay is slow. In individuals where it takes weeks to decay, the decayed watery portion leaches away and a callus forms when the growing tissue is reached. Where field conditions are right, the fungus will continue its slow advance into the foot of the stem, causing no decay and slight or no discoloration. As conditions unfavorable to the plant arise, the fungus grows in the vascular bundles and causes discoloration. Plate 39, B, shows a 6-weeks'-old stem to the left portion of which the decomposed and dried piece clings. Discoloration of the pith is found only at the very foot of the stem, and the upper vascular bundles are free from any trace of the fungus. In the field this plant would be regarded as healthy. In plants of this type the lowest roots on the stem are cut off from supplying water, and thereby cause some of the temporary queer symptoms to be noted in the foliage. The plant may recover, draw on the roots above more heavily, and continue growth. Nothing more may happen throughout the season; harvest may arrive, and the plant yield normally. In other cases where the soil is wet and compact the fungus is more active; it decays the foot of the stem, cuts off stolons, decays new potatoes, and finally kills the plant. Plate 39, A, pictures a

plant taken from a field where irrigation water got beyond control and flooded a portion of the field. The fungus advanced rapidly, decayed the stem, and caused the death of the plant. The advance was so rapid that the roots were killed for only a short distance, remaining uninfected 2 inches from the stem. In severe cases action is rapid and universal; whole fields succumb, causing the well-known epidemics. When stems of rapidly killed plants are pulled up, they are black, soft, and wet, as is illustrated in Plate 38, D. This plant, naturally infected by *F. oxysporum*, is strikingly like the plant shown by Link (5, *fig.* 7), as caused by artificial infection with this organism. Other organisms follow closely behind the species of Fusarium and complete the decay of any tissue not thoroughly invaded by that fungus.

ISOLATION OF CAUSAL ORGANISMS

During the growing seasons of 1916, 1917, and 1918 more than 1,500 cultures have been made in attempts to isolate the causal organisms. Plants in every condition, from newly planted diseased seed to new tuber infection at harvest, were used as sources of culture. The material was selected in the field, and taken at once to the laboratory. It was carefully washed under slowly running water and patted to comparative dryness between damp towels. The material was prepared for culturing by breaking it open and, with a sharp chisel-pointed platinum needle, transferring small pieces from the desirable areas to tubes containing sterile melilotus stems.

In making these cultures too many precautions can not be taken to keep within very small areas with the needle. The line of demarcation between apparently firm tissue and diseased tissue is definite and narrow. Cultures made from the firm tissue immediately before the line, and on the line, were usually pure, and sporulated readily. Tissue back of the line gave many contaminations; too far in advance gave no growth at all in culture. In decaying seed pieces it is well to keep within 2 mm. of the line of decay. In the green tissue of growing stems little trouble will be experienced if the stems are not broken or torn before culturing; and, as infected stems soon become woody, a stiff sharp needle is necessary in culturing from them. Any blackened tissue will usually yield a culture. These infected tissues invariably yield species of Fusarium, though, if decay has advanced to the point of disintegration, contaminating organisms will be present. *Stysanus stemonitis* is frequently found in both attacked stems and seed pieces. Bacteria are rarely found in firm or semifirm tissue.

FIELD EXPERIMENTS

A series of experiments were performed with several lots of potatoes to determine as nearly as possible the origin of the disease developing during the growing season, basing the deductions upon the conditions

of the seed at planting time and the symptoms displayed during growth. These experiments were carried out in the field under conditions approximating commercial field practice, and no methods of culture or treatment were used at any time after planting which would not have been used by a commercial grower. For the purpose of this experiment it was conceded that parts of the same seed potato, grown under like conditions, would follow within reasonable limits pretty nearly the same course of procedure in growth, disease symptoms, and general appearance. A difference in two plants from twin seed pieces must be accredited to different conditions encountered during the growing season after planting. Various lots of seed were assembled in 1916 to test out this assumption. Among others, they consisted of one lot of certified Wisconsin Pearl, one lot of certified Wisconsin Rural, two lots of Early Ohio from the Red River Valley in Minnesota, one lot of Rural from the Carbondale District of Colorado.

All tubers were cut from bud to stem end, dividing the tuber into two equal parts. All tubers above 6 ounces were cut into four pieces. These were cut in the field and planted immediately side by side in parallel adjacent rows. They were given as good care as possible during the growing season. The summer was excessively warm until July 30, 1916, at which time 3.09 inches of rain fell. The remainder of the summer was comparatively cool. Notes were taken four times during the summer: Once when the plants were about 6 inches high, then when they averaged 12 inches high, again when they were full grown, and finally when no normal change was to be expected. No reference was made to any previous note; other members of the force were asked to assist in the work, and every method employed by which an impartial diagnosis could be made.

KEY TO TABLE I.

For the purpose of summarizing and presenting the performance of these lots of tubers, a new form of table, known as an aggregation table, has been constructed. This table must not be confused with a correlation table, which it resembles in general appearance, but not in context. In any single row of potatoes six different ultimate types of plant were recognized. These have been designated as "H," "HD," "DH," "D," "A," and "O." The meaning of these symbols are as follows: "H" denotes a plant which appeared healthy throughout the growing season; "HD" denotes a plant which was healthy during the first part of the season, but finished by being diseased; "DH" denotes a plant which gave manifestations of disease during the first part of the season, but finished by being healthy; "D" denotes a plant which was diseased throughout the season; "A" denotes a plant so badly diseased as to be merely existing, with no hope of progeny; "O" denotes no germination, or a case in which the seed piece suffered the maximum of disease and rotted in the ground. All plants in a row fell into one of these divisions. In comparing the plants from twin seed pieces in the two adjacent rows at the same time it is seen that in classification certain coincidences, or lack of them are significant. In the case of some plants classed as "H" in one row, the twins in the adjacent row were "H" also; in more cases they differed for all the

other five groups. Originally in numbering rows in the field the even and odd followed naturally, so that in the tables the parallel adjacent rows are most easily designated by the terms "even" and "odd." In the tables the "even" rows are read vertically—that is, the designating letters are placed across the top, and the aggregate totals for each class across the bottom; the "odd" rows are read horizontally, the letters at the left and the aggregate totals at the right. However, as noted before, many of the twins differ individually in their performance, so that in order to express this deviation the total of one class in one row is split up according to the numbers required to express the reciprocal in the other row. A concrete example is given in Table 1 A. In the even row there are 352 H, 4 HD, 5 DH, 1 D, 13 A, and 12 O plants, a total of 387. In the odd row there are 320 H, 5 HD, 7 DH, 1 D, 23 A, and 31 O plants, a total of 387. In comparison with 352 H plants in the even row, twin for twin in the odd row, 296 plants are also H, while 4 are HD, 7 DH, 1 D, 20 A, and 24 O. Turning about, it is seen that, of the 320 H plants in the odd row, twin for twin in the even row, 296 are H, 3 HD, 3 DH, 1 D, 11 A, and 6 O. The same system follows for the other classifications. It is revealed, then, how nearly alike twin seed pieces perform, for where they are alike the numbers appear in either the HH, HDHD, etc., squares down to OO. Differences are shown when they appear elsewhere.

TABLE I.—*Aggregation of seed piece performance of Irish potatoes*

A. WISCONSIN PEARL

[1 equals 0.[illegible] per cent of 387]

	H		HD		DH		D		A		O		Total	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
H	296	76.49−	3	0.78−	3	0.78−	1	0.2[illegible]	11	[illegible]	6	[illegible]	[illegible]	[illegible]
HD	4	[illegible]	1	[illegible]									[illegible]	[illegible]
DH	7	[illegible]											[illegible]	[illegible]
D	1	[illegible]											[illegible]	[illegible]
A	20	[illegible]			2	[illegible]					1	[illegible]	[illegible]	[illegible]
O	24	[illegible]							2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	352	[illegible]	4	[illegible]	[illegible]	[illegible]	1	[illegible]	13	[illegible]	12	[illegible]	[illegible]	[illegible]

B. INFECTED WISCONSIN PEARL

[1 equals 3.[illegible] per cent of 27]

	H		HD		DH		D		A		O		Total	
H	25	92.60−											25	92.60−
HD	1	3.7[illegible]+											1	[illegible]
DH	1	3.70+											1	[illegible]
D														
A														
O														
Total	27	100.00											27	[illegible]

C.—CERTIFIED WISCONSIN RURAL NEW YORKER

[1 equals 0.225225 per cent of 444]

	H		HD		DH		D		A		O		Total	
H	89	20.05−	1	0.23−	24	5.4[illegible]	1	0.23−	19	4.[illegible]	30	6.76−	164	36.94−
HD														
DH	16	3.60+			32	7.21	2	[illegible]	18	[illegible]	16	[illegible]	84	[illegible]
D					2	.45+							2	.45+
A	18	4.05+			11	2.4[illegible]	2	.4[illegible]	2	[illegible]	11	[illegible]	44	9.91
O	67	15.09+	1	.23−	19	4.2[illegible]	4	.9[illegible]	23	[illegible]	40	9.01−	154	[illegible]
Total	190	42.79+	2	.45+	88	19.82−	9	2.03−	[illegible]	13.[illegible]	97	21.85−	444	[illegible]

TABLE I.—*Aggregation of seed piece performance of Irish potatoes*—Continued

D.—INFECTED CERTIFIED WISCONSIN RURAL NEW YORKER

[1 equals 6.25 per cent of 16]

	H		HD		DH		D		A		O		Total.	
	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.
H	6	37.50			1	6.25			1	6.25	1	6.25	9	56.25
HD														
DH	1	6.25			1	6.25					1	6.25	3	18.75
D														
A	1	6.25											1	6.25
O	2	12.50									1	6.25	3	18.75
Total	10	62.50			2	12.50			1	6.25	3	18.75	16	100.00

E.—RED RIVER VALLEY EARLY OHIO.

[1 equals 0.259067 per cent of 386]

H	141	36.53—	2	0.52—	25	6.48—			14	3.63—	37	9.59—	219	56.74—
HD	2	.52—									1	.26—	3	.78—
DH	29	7.51+			11	2.85—			1	.26—	6	1.55+	47	12.18—
D	2	.52—					1	.26—					3	.78—
A	7	1.81+							1	.26—	4	1.04—	12	3.11—
O	62	16.06+	1	.26—	16	4.14+			3	.78—	20	5.18+	102	26.42+
Total	243	62.95+	3	.78—	52	13.47+	1	.26—	19	4.92+	68	17.62—	386	100.00

F.—INFECTED RED RIVER VALLEY EARLY OHIO.

[1 equals 2.857142 per cent of 35]

H	16	45.71+			4	11.43—			1	2.86—	2	5.71+	23	65.71+
HD														
DH	2	5.71+											2	5.71+
D														
A											1	2.86—	1	2.86—
O	4	11.43—	1	2.86—	2	5.71+					2	5.71+	9	25.71+
Total	22	62.86—	1	2.86—	6	17.14+			1	2.86—	5	14.29—	35	100.00

G.—CARBONDALE RURAL NEW YORKER

[1 equals 0.3125 per cent of 320]

H	29	9.06+			29	9.06+	1	0.31+	5	1.56+	27	8.44+	91	28.44—
HD														
DH	10	3.12+			40	12.50	1	.31+	3	.94—	16	5.00	70	21.88—
D					2	.62+							2	.62+
A	5	1.56+			8	2.50	1	.31+	1	.31+	9	2.81+	24	7.50
O	29	9.06+	1	.31+	39	12.19	1	.31+	10	3.12+	53	16.56+	133	41.56+
Total	73	22.81+	1	.31+	118	36.87+	4	1.25	19	5.94—	105	32.81+	320	100.00

H.—GREELEY LATE OHIO.

[1 equals 1.111111 per cent of 90]

H	45	50.00	1	1.11+	7	7.78—			3	3.33+	5	5.56—	61	67.78—
HD	1	1.11+											1	1.11+
DH	6	6.67+			6	6.67+					2	2.22—	14	15.56—
D														
A	1	1.11+			1	1.11+							2	2.22+
O	7	7.78—			2	2.22+					3	3.33+	12	13.33+
Total	60	66.67—	1	1.11+	16	17.78—			3	3.33+	10	11.11+	90	100.00

TABLE I.—*Aggregation of seed piece performance of Irish potatoes*—Continued

I.—INFECTED GREELEY LATE OHIO

[1 equals 1.960784 per cent of 51]

	H		HD		DH		D		A		O		Total	
	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.
H	26	50.98+	1	1.96+	2	3.92+			2	3.92+	2	3.92+	[illegible]	64.71−
HD														
DH	4	7.84+			5	9.80+							9	17.65−
D														
A					1	1.96+							1	1.96+
O	6	11.76+			1	1.96+					1	1.96+	8	15.69−
Total	36	70.59−	1	1.96+	9	17.65−			2	3.92+	3	5.88+	[illegible]	100.00

J.—GREELEY PEARL

[1 equals 0.7246377 per cent of 138]

H	63	45.65+	6	4.35−	4	2.90−			4	2.90	11	7.97+	88	63.77−
HD	1	.72+	2	1.45−							1	.72+	4	2.90−
DH	4	2.90−									2	1.45−	6	4.35
D											1	.72+	1	.72+
A	5	3.62+	1	.72+					2	1.45	3	2.17+	11	7.97+
O	10	7.25−	2	1.45−					3	2.17+	13	9.42+	28	20.29
Total	83	60.14+	11	7.97+	4	2.90−			9	6.52+	31	22.46+	138	100.00

K.—INFECTED GREELEY PEARL

[1 equals 1.8867924 per cent of 53]

H	22	41.51−	3	5.66+	3	5.66+			4	7.55	6	11.32+	38	71.70−
HD			1	1.89−									1	1.89−
DH														
D											1	1.89	1	1.89−
A	3	5.66+							2	3.77	1	1.89	6	11.32+
O	3	5.66+							1	1.89	3	5.66+	7	13.21
Total	28	52.83+	4	7.55−	3	5.66+			[illegible]	[illegible]	11	20.75+	53	100.00

L.—INFECTED COLORADO PEARL

[1 equals 0.6666666 per cent of 150]

H	115	76.67−	14	9.33+							[illegible]	[illegible]	[illegible]	[illegible]
HD	14	9.33+	5	3.33+									[illegible]	[illegible]
DH														
D														
A														
O														
Total	129	86.00	19	12.67−							[illegible]	[illegible]	[illegible]	100.00

M.—IDAHO-GROWN IDAHO RURAL

[1 equals 0.8264462 per cent of 121]

H	105	86.78−	9	7.44−							[illegible]	[illegible]	116	95.87−
HD	5	4.13+											5	4.13+
DH														
D														
A														
O														
Total	110	90.91−	9	7.44−							2	1.65+	121	100.00

WISCONSIN PEARL (TABLE I, A–B)

Aggregation Table I, A, illustrates the performance of the certified Wisconsin Pearls potatoes in 1916. There was a total of 774 seed pieces planted, the result of dividing 387 tubers. The striking thing to be noted in this section of the table is the fact that with the majority of diseased plants in either row the twin was healthy. In only 11 cases did both twins fall outside of a healthy square, five of these being in the square OO. If vascular infection was to act here only the 5 twins in the OO square could properly be said to come under control of it, because it is the only instance where the performance was the same for both twins. In the cases of the 80 pairs of twins, 1 of which was in some way diseased and the other healthy—that is, those in both rows where 1 twin was an H plant, exclusive of those in HH—it must be regarded that the disease was newly contracted. Before planting, all tubers were cut at the stem end to inspect for vascular discoloration, indicating the presence of a possible disease organism. Cultures were made from diseased tissue. Only 27 tubers, or 6.98 per cent, showed any discoloration. Tabulating then according to the place the tuber occupies in Table I, A, their places are shown in Table I, B.

According to the old conception of the danger of planting diseased seed, the 27 tubers, planting the 54 plants here shown should have given some sign of disease. The 2 which fall without the HH square are healthy plants, for one-half of the tuber would indicate no tendency to disease because of the vascular parasite, but because field conditions acted as in the case of 78 similarly situated plants, as shown in Table I, A.

WISCONSIN RURAL (TABLE I, C–D)

The certified Wisconsin Rural potatoes were treated in the same manner throughout, and were tabulated in the same way: 444 tubers were used, planting 888 hills, and their performance is shown in Table I, C.

The plants in this table are well distributed except in the HD columns. The performance of the twins as representing the strictly inherent tendencies of the tuber seems not to be indicative of any considerable failure because of previous faults. There are 40 pairs in OO, and 30 and 67 pairs in HO and OH, respectively. The factors which placed the 40 pairs in OO did not act on them as parts of 40 tubers, but as 80 individual plants, the same as took place with the 30 and 67 pairs, one-half of which were healthy. This variety is peculiar in showing such a contrast between susceptibility to disease and vigor to survive and grow away from it. The tubers of this lot were planted within 10 feet of the lot represented in Table I, A.

Table I, D, represents the place in which those seed tubers fell which showed discoloration in the vascular system. These 16 tubers (3.60+

per cent) are placed in the table according to the place they occupy in Table I, C, and it is regarded as of no significance that they fall where they do.

EARLY OHIO (TABLE I, E-F)

The Early Ohio seed obtained from the Red River Valley consisted of two lots. These lots were grown separately, but their performances were so nearly alike that they have been combined and presented in Table I, E, as one lot.

This table shows plants falling in the DHDH, DD, AA, and OO squares, a tendency not noted in the previous tables. In the case of the plants falling in DHDH, it would appear that some special weakness had developed in the 22 plants grown from these 11 tubers which placed them there. Inherent weakness, then, can not be predetermined by mere examination of the tubers, because Table I, F, which represents the location of the tubers showing vascular discoloration (0.07 – per cent), placed according to their location in Tables I, E, has none represented in DHDH. These plants outgrew their earliest diseased condition, and finished the season in apparent healthy condition. Table I, E, does not indicate, however, any strong vigor on the part of this lot.

Table I, F, represents the place the 35 tubers of Table I, E, which showed vascular discoloration fell, placing them according to their location in Table I, E.

RURAL NEW YORKER (TABLE I, G.)

One lot of seed of the Rural New Yorker variety was obtained from the Carbondale District of Colorado. It consisted of 320 tubers, free from vascular discoloration, and was regarded as stock of superior quality, selling at an advanced price. Table I, G, illustrates the almost complete failure of this seed through seed-piece infection and rot in the Greeley District.

In this table, where so much disease is represented, the conspicuous absence of plants falling in the HD columns (1 in the even row), and in the DD square, is significant. Root infection did not occur; no vascular discoloration was present in the seed. The great preponderance of plants in the OO square and the O columns, shows clearly that a most serious inherent weakness is present in the seed to withstand infection from the soil. The number of plants that did not eventually become healthy, having previously grown and been diseased, are very few. There is a strong tendency to die or survive (H or DH), for the plants that are H or DH were vigorous at the end of the season. The others either failed, as in O, or gave evidence of a gradually declining health, as in D and A. The lack of plants in the HD columns (1 in the even row) is further evidence that a healthy plant maintains its position.

LATE OHIO DISEASED SEED (TABLE I, H-I)

In the fall of 1915 several fields were visited for the purpose of staking diseased hills of potatoes. The hills selected all showed blackening of the stems and death of the tops, with many cases of rot in the tubers. At harvest the badly decayed tubers were discarded for the reason that they were in no condition to keep through the winter. The tubers showed a large percentage of vascular discoloration, and the remainder were believed to be infected, though not seriously. All came from hills affected by Fusarium-blight. Cultures were made from the stem end of all showing discoloration, and all yielded species of Fusarium. The tubers were cut and planted as twins in adjacent rows and given the same culture as the lots mentioned above. Table I, H, shows the performance of such seed of the variety Late Ohio in the year 1916.

The complete absence of any plants falling in the D columns is the outstanding feature of this table. At best, only the 6 pairs represented in DHDH square could be said to show the results of vascular infection, especially from the occurrence of 5 of them in the DHDH square in Table I, I. Compared with Table I, E, which represents a healthy Early Ohio variety, the advantage in health is with the home-grown seed.

A table representing the places in which the 50 tubers (56.66+ per cent) showing decided vascular discoloration fell, is shown by Table I, I.

PEARL DISEASED SEED (TABLE I, J-K)

One lot of diseased seed consisting of 138 tubers, Pearl variety, acquired in the same manner as the Late Ohios, were cultured from the stem-end, and planted under the same conditions as other lots. Table I, J illustrated the performance of this badly diseased seed stock.

Two things are conspicuous here: The lack of plants in the D columns (one in DO), and the comparatively large number in the O and the HD columns. These are not to be accounted for here altogether because of their vascular discoloration, because Table I, K, which represents where the 53 tubers (38.41 – per cent) fell which showed discoloration, does not account for the majority. Plainly these plants have been weakened by disease, their power of resistance lessened, and their vigor impaired. Examination showed that soil infection acted here to produce the disease, but a comparison of Table I, J, with Table I, A, reveals the great weakness acquired by these plants, which made them so easily attacked. These tubers were extreme cases, being stock that would not ordinarily get into commercial seed. The circumstances surrounding this lot of of seed tends to explain the true reason why farmers of the Greeley District prefer to plant newly introduced seed every two years.

Table I, K, represents the places in which that seed fell which showed pronounced vascular discoloration, according to the place they occupy in Table I, J.

PEARL DISEASED SEED (TABLE I, L)

In 1917 one lot of seed, Pearl variety, was secured, each tuber of which showed positive vascular infection by species of Fusarium, as proven by isolation cultures. Conditions were generally more favorable for potato growth early in the 1917 season than they were in the 1916 season, and less favorable late in 1917 than in 1916. Table I, L, shows the performance of this badly diseased stock.

IDAHO RURAL (TABLE I, M)

One lot of seed from Idaho, known as Idaho Rurals, and healthy throughout, were treated in the same manner. No tuber showed disease or infection in the vascular system. The performance of this lot of seed is illustrated in Table I, M.

The similarity between Tables I, L, and I, M, is striking. The presence of plants in the HD columns is attributed to the unfavorable late season in 1917. This is taken to account for the uniform health as represented for the diseased Pearl variety in Table I, L.

There is no reason to suppose that if mere chance had operated so as to have each seed fall where its twin fell, and vice versa, that the result would have been the same in any table. Each seed piece was surrounded by a different set of factors which operated to bring about disease or apparent health. For that reason it is unlikely that the results of a single year can be duplicated, though the average of similar years ought to strike a fair average.

DISEASE RESISTANCE

In the fall of 1915 a field of potatoes was chosen upon which to conduct an experiment in disease resistance. It was one calculated to offer crop failure if one was reasonably possible. One end of the field was white with alkali, the soil was heavy, and drainage was poor. A portion of the field already had potatoes on it, supposedly of the Pearl variety. It presented a very ragged appearance owing to skips, diseased plants, and mixture. Two of the best-looking rows were selected to work upon, and all the diseased and mixed plants were staked. After frost the staked plants were taken out by hand, and the remaining healthy plants were harvested with a machine. In 1916 this seed was planted on an adjoining plot. All the plants came up healthy and with increased vigor. Some plants succumbed to blight during the season, but at least 90 per cent reached harvest. Again in 1916 several rows were inspected, the diseased and mixed plants staked, and the healthy ones harvested as before. These were planted in 1917 in a plot adjoining the one used in 1916. In comparison with other potatoes in the field, the vigor and health of the selected seed was notable. Very few diseased plants were to be found, and skips in the rows were rare. These plants promised

well for another year, when a mistake was made in watering by the farmer, the ground became water-logged, and the entire field was lost through blight in the mature stage.

SOIL CONDITIONS AND IRRIGATION

Soil conditions materially assist the plant or the fungus. If the ground is well moistened and loose when the seed is planted, a strong vigorous start may be obtained by the plant which will carry it well beyond the immediate reach of the fungus. It has been the common practice to withhold irrigation until the new tubers begin to set. If the plant can endure withholding artificial watering until the new tubers set, it is well to delay, but to postpone it until the plant is suffering acutely, brings it to a condition from which it never wholly recovers. The fungus will make headway in a drouthy plant. After irrigation water has been supplied, it is expedient to cultivate deeply, because irrigation water packs the soil tightly. Too great an application of water on heavy soil may leave the soil puddled, in which condition it must remain for several days before cultivation is possible. If this is accompanied by a rising soil temperature, the ill effects are increased. Occasionally a heavy rain will puddle the soil late in the season preceding harvest. This may occur on ground irrigated too late. In such an event it is common for the plants to blight generally and die. The damage now is not in the death of the foliage or the death of the plant, but in the rot which will attack the new tubers. This is a black-rot which may enter by way of the stolons, a common method, or through wound or lenticel. When such tubers have begun to rot, they are a total loss. If the rot has not been detected in the field, it may occur later in the bin, causing a worse trouble. All the tubers of a plant may not be attacked, however, and in such a case control consists in getting them out of the ground without delay. Early varieties in which the new tubers have time to come to full ripeness are more susceptible than late varieties.

At this time correct irrigation practice is unknown. No rule can be formulated, because each piece of ground requires different treatment. During some years it is expedient to "irrigate up," meaning to water the field immediately after planting. If the soil is too dry, irrigation is necessary for germination and will carry the plant for the maximum length of time before rewatering. Harm results if the water applied in addition to the soil moisture present creates an excess. Irrigation of a plowed field in which nothing has been planted is impractical, owing to the absence of row ditches, and the fact that a certain time must elapse before anything can be planted. Cultivation should be given after each irrigation, so long as it can be done without damaging the plants below ground. Sandy soils need less cultivation than heavy soils. The best

judge of the soil on any farm is the farmer who has worked with it. Each parcel of land has its own peculiarities, and advice on the handling of land should be specific. The very best conditions obtainable for the potato should prevail throughout the season, and so long as the farmer can control the environmental conditions no trouble is likely to result.

CONTROL

Control of Fusarium-blight has not been attained. Different methods have been employed, three of which offer reasonable hope of success.

First, selection of plants whose progeny will offer resistance to the invading organisms. For this purpose, experiments are being carried out with standard accepted varieties known to be suited to the locality. It is possible to select for resistance and have it gradually evidenced in the performance of the plants, as in the field experiment noted above. That is satisfactory so long as some overwhelming circumstance does not intervene and wipe out the work of years. At best, resistance is but a relative thing.

Second, control by seed treatment. The attempt has been made, not to kill something that may be on the seed as in the orthodox seed treatment, but to coat the cut seed with a preservative or fungicide which would remain vital throughout the season, preventing infection. Could this be done, it would offer an easy solution to the problem. Experiments were carried out in 1917 to test out the effect of different solutions. None of them gave satisfaction. Several lots of potatoes were treated and planted on May 18, 1918, with several different mixtures and compounds, all of which for some reason or other were suspected of having some possible preservation value. The seed used was the Rural variety, and was cut in the usual way. The method of application depended upon the nature of the fungicide, and this is noted under "Remarks" in Table II. One lot was treated with a spore suspension of *F. oxysporum* for comparison. On June 19, 1918, a similar experiment was made with a few lots. The results of these experiments are given in Table II, and are the data taken from counting 600 plants.

TABLE II.—*Effect of various seed treatment on germination of Irish potatoes*

PLANTED MAY 18; COUNTED JUNE 15

Treatment.	Percentage of germination.	Remarks.
Nicotine sulphate	75	Dipped. Solution 1 to 8,000.
Bordeau mixture	68	Dipped. Formula 5-5-50.
Charcoal	90	Dusted. Seed remained unusually firm.
Hypochlorous acid [a]	0	Dusted. Seed killed by treatment and rotted by several organisms.
F. oxysporum	35	Sprayed. Strong spore suspension.
Iron sulphate	40	Dusted. Some seed killed.
Lithum carbonate	0	Dusted. Thoroughly and quickly rotted.
Mercuric chlorid	60	Dipped. Solution, 1 to 1,000.
Mustard oil	70	Sprayed.
Controls	85	Dipped in water.
Whole seed	97	Dipped in 3 per cent solution of copper sulphate.

PLANTED JUNE 19; COUNTED JULY 15

Treatment.	Percentage of germination.	Remarks.
Charcoal	82	Dusted.
F. oxysporum	0	Sprayed.
Onion juice	55	Dipped. Expressed juice of onions.
Control, cut	88	Dipped in water. Average field performance.
Whole seed	99	No treatment.

[a] SMITH, J. L. et al. ANTISEPTIC ACTION OF HYPOCHLOROUS ACID AND ITS APPLICATION TO WOUND TREATMENT. *In* Brit. Med. Jour., 1915, no. 2847, p. 129-136. July 24, 1915.)

In the first planting the charcoal treatment gave better germination than the controls, but fell behind in the second planting. None of the others were worth the trouble of treatment. The whole seed gave much better stands and of more healthy vigorous plants.

Third, in applying the best-known cultural practice to the propagation of the potato. For this no rules can be given. Each farmer should judge the condition of his land, its moisture content, tilth, and apparent needs. Rotation with grain and legumes is advisable, allowing the land to be cropped with alfalfa as many years as possible before potatoes are planted. Methods of irrigating and cultivation during the growing season should be investigated at the time for the field in question. Plate 41, A, shows a field planted with good seed, but owing to the dryness of the soil at planting time infection set in, and the fungus destroyed from 60 to 80 per cent of the seed, with the resulting poor stand.

GENERAL DISCUSSION

Infection of potatoes by *F. oxysporum* from the soil through the seed piece has never been recorded before, so far as is known. That it is of widespread general importance on alkali soils is believed, from conditions noted in several potato-growing regions of the West. In parts of the

San Luis Valley, where so many unfavorable conditions are at work, owing to subirrigation and a high water table, the large majority of the potatoes show signs of this infection. Other investigators have found vascular infection of the seed to be the cause of much trouble, and the seriousness of that manner of infection elsewhere can not be judged from these experiments. In the Greeley District, where the Fusarium-blight has been so serious for many years, a fortunate change has taken place. This is regarded as being due to the introduction of other crops, potatoes being brought into the crop rotation only once in four years or more. The use of seed beans, sugar beets, grain, and alfalfa in the definite rotation is extending the time between the same crops with corresponding advantage to each. The potato was desirable as a high-priced crop, and still is, and the percentage of loss is less with rotation.

Alkaline soils are a favorable medium for *Fusarium* spp. Pratt (*12*) found them to be abundant in virgin desert soils. The prolific and luxuriant growth of species of Fusarium on alkaline media in pure cultures is an indication of what may be expected in part in alkaline soils where humus is abundant. In disease investigations of this kind it was found desirable to conduct the experiments as much as possible in the field, for the reason that conditions there came about naturally, and the response was immediate and proportionate. Greater care must be taken to note and record every conceivable change of condition. In the gross the changes from day to day are observable and are recorded by suitable instruments; but the changes that occur in the plant are more delicate and rapid than gross observations indicate. Each square foot of soil has its own conditions, not distinguishable from the adjoining square foot perhaps, but of sufficient difference to be felt by the plant.

The plant feels these things and responds. If resistant stock is to be selected, these changes and conditions should be known, and the finer symptoms indicated by the plant must be recognized for the purpose of analysis.

Temperatures of the soil are vital as regards infection. The critical temperature for infection has not been determined and it varies for the manner of infection. Seed-piece infection will occur at a considerably lower temperature than root infection. In the Carbondale District, at a higher altitude and in cooler soil than the Greeley District, only those plants show Fusarium-wilt symptoms which have decayed seed pieces. Usually the seed piece remains sound throughout the season there, and the plants are free from blight. In the Greeley District the soil temperatures are higher, and the seed pieces are generally attacked. Root infection occurs with temperatures higher than the average. As the plants get larger and shade the ground, and the roots penetrate deeper the danger from root infection is lessened.

There has been a belief that less blight occurs when the potatoes follow alfalfa than otherwise, and that the older the alfalfa was the

better would be the potatoes. The current reasons for this are many and varied, but the principal one given is that there is less blight in the soil. This may mean fewer fungus organisms in the soil, but that does not seem to be the case. In several instances potatoes grown from good stock on soil previously in alfalfa for nine years have been observed as badly diseased as the same seed on soil only one year in alfalfa. The organism was present as abundantly as ever, and wherever the condition of poor cultivation or heated soil was present, the disease was manifest. The true value of alfalfa preceding potatoes lies in the fertilizer increment and mechanical improvement added to the soil, and not to any dearth of *Fusarium* spp.

The use of whole seed is suggested, not as a means of controlling the blight, but of avoiding it. By the use of whole seed is meant not culls and other small potatoes, but tubers in good condition, well selected, and preferably of 1½-ounce weight or greater. Whole seed has been many times condemned as yielding quantities of unmarketable small potatoes, and from the horticultural point of view this is a serious fault. Under irrigation, however, the writer believes that whole seed can be made to yield nearly as many marketable tubers as cut seed. The increased stand resulting and the fact that no labor is required in cutting would promise a return commensurate with the initial increased cost of the seed. In one commercial field in 1918 the yield from whole seed was 100 per cent greater than that from cut seed of the same variety. This field is shown in plate 41, B. The cut seed was planted on the left and the whole seed on the right. The photograph was taken at midseason. Sandsten (*13*) believes that whole seed is preferable to cut seed in dry-land farming because it prevents seed-piece rot.

SUMMARY

The disease of potatoes in the field caused by *Fusarium* spp., principally *F. oxysporum*, whereby death of the plant or decay of any part of it is brought about, is to be regarded as different phases of the same disease. For that reason it is desirable to apply a generally applicable name covering all stages. The term "Fusarium-blight" expresses this adequately.

Two methods of infection are recognized: Infection from the soil of roots and root hairs, and infection of the seed piece, whereby the plant becomes diseased. The latter method is regarded as the most serious and responsive to environmental conditions in the Greeley district of Colorado.

Three methods of control are suggested, none of which have yet proved wholly effective. First, selection for disease resistance, a method shown to be effective only to a minor degree. Second, superior cultural conditions for the potato plant, whereby it may always maintain a degree of resistance to pathogenic organisms through activity and

health. Lengthened rotation periods employing other crops followed by alfalfa improve the nutritive and mechanical properties of the soil, while a judicious irrigation practice adapted to the particular field and season involved combined with suitable cultivation should constantly maintain a steady and adequate, but never excessive, supply of moisture and insure suitable aeration. This is the method available to the farmer, so far as he knows what constitutes the best conditions for his land throughout a given season. Third, by the use of whole seed, free from wound or injury, thus preventing seed-piece infection, or at least maintaining the plant free from infection for the maximum length of time. The combination of the two last-named measures probably constitutes the most effective measures for control of Fusarium-blight.

It is believed that more than one species of Fusarium is able to bring about each phase of the blight. *F. oxysporum* in pure culture under suitably controlled and natural conditions has been found to do this.

Three general stages of the Fusarium-blight are recognized. First, the stage in which decay and death of the seed piece and new plant occurs before the new shoot emerges from the ground. Germination may or may not have occurred. Second, the later stage, in which the young plant shows many and diverse symptoms of infection by *Fusarium* spp., often resulting in death. Some of these manifestations are not fatal, and recovery is possible. Third, the mature stage, resulting in death, usually at an advanced state of growth, often with infection and decay of the new tubers.

Different varieties of potatoes show marked variation in their behavior under the same general conditions. There is an inherent weakness in different strains of the Rural variety toward Fusarium-blight, accentuated by the conditions under which the seed was grown. The Pearl variety shows these weaknesses, but to a minor degree, unless brought to a poor condition by previous subjection to disease.

Vascular infection of the seed is not the starting point of disease, but is one of the conditions assisting in bringing about decreased resistance to new infection from the soil.

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PLATE 37

Effect of Fusarium-blight on seed pieces of potato:

A.—Early Ohio seed pieces: Control above; pieces inoculated with *F. oxysporum* below.

B.—Early Ohio plant. See piece inoculated with *F. oxysporum*.

C.—Early Ohio seed pieces: Control (left) and inoculated (right) seed pieces. The control shows the method used in inoculation.

D.—Seed piece well decayed, resulting from soil infection.

E.—Seed-piece rot in field.


A
B
C
D
E

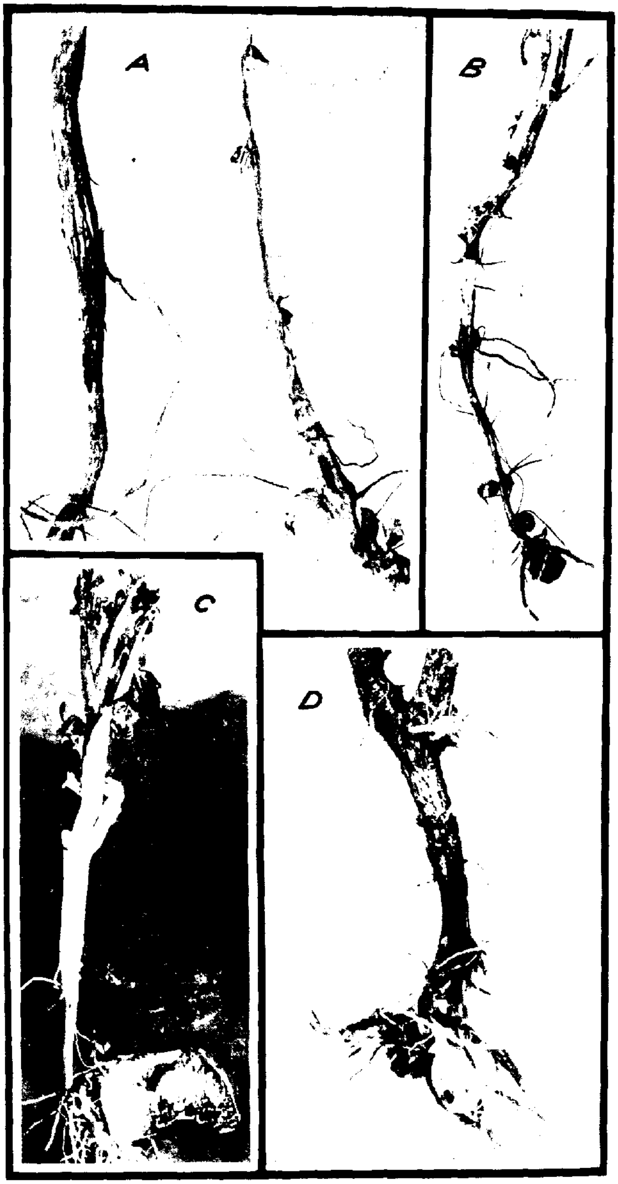

A
B
C
D

PLATE 38

A.—Inoculated and uninoculated stems of same potato plant. Stem at right shattered by *F. oxysporum*.

B.—Potato plant (control), showing method of inoculating with wedge of melilotus stem.

C.—Seed-piece rot in field. The young potato plant has not yet been attacked.

D.—Potato plant naturally infected by *F. oxysporum* in the field.

PLATE 39

Potato stems showing seed-piece rot:

A.—Stem split to show rotting due to organism entering through seed piece from soil. Note decay of roots from point of attachment outward.

B.—Stem split to show slight discoloration at base where infection from soil-infected seed piece occurred.

C.—Seed piece of potato plant shown in Plate 40, B. The center top leads to the center of decay.

D.—Seed-piece rot in field. The seed piece is well decayed, but plant is unaffected and the roots are healthy.


C
D


A
B
C
D

PLATE 40

Potato plants affected by Fusarium blight:

A.—Potato plant late in season with rolled leaves. Fusarium blight.

B.—Top of potato plant consisting of three stems. One leaf on one stem is wilted See Plate 39, C.

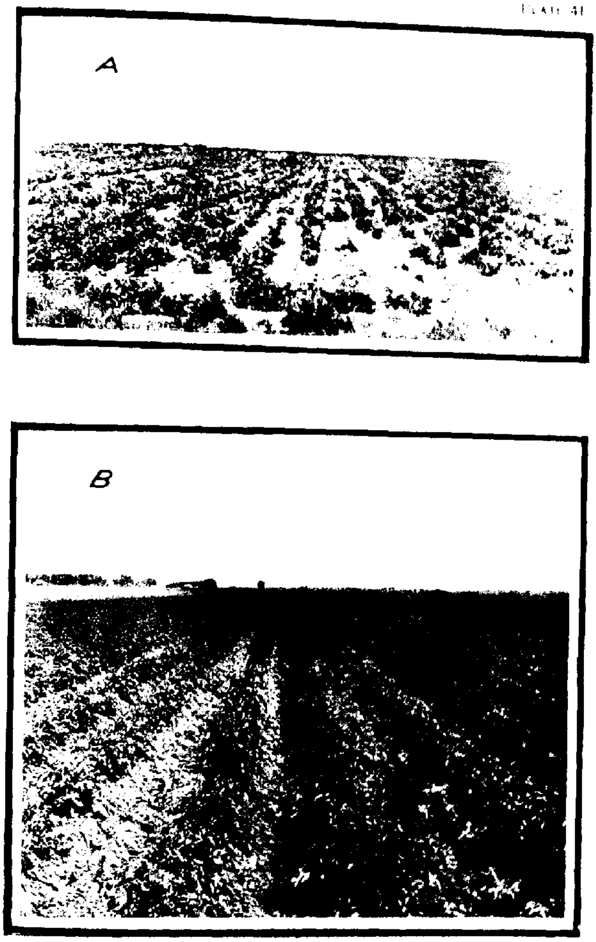
C.—Potato plant of two stems, one at left showing Fusarium blight, or wilt caused by seed-piece infection; one at right healthy.

D.—Plant with rolled leaves gradually dying from Fusarium blight. Severe case late in season.

PLATE 41

A.—A field of potatoes showing the result of unfavorable cultural and soil conditions, by which seed-piece rot destroyed 60 per cent of the stand.

B. A field of potatoes planted with whole seed (rows to right) and cut seed (rows to left) at midseason. The hills planted with whole seed gave a 100 per cent greater yield than those planted with cut seed.


A
B

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